As this information, according to the inquiries, was obviously not sufficient, quantitative data for an advanced growing technique are herewith given to facilitate the investigations on barium titanate in other laboratories.

With the relative proportions of one mole $BaCl_2$ to about 0.53 mole $BaCO_3$ and 0.26 mole TiO_2, the best results were obtained by cooling the melt from 1200°C down to approximately 800°C within a few hours. Usually we used 50 grams of $BaCl_2$, 25 grams of $BaCO_3$, and 5 grams of TiO_2.

The dishes in which the growth takes place should preferably be of purest platinum or carbon crucibles used in a nitrogen atmosphere. By the first method, a certain amount of platinum is dissolved and causes a discoloration of the crystals which can be removed to some degree by tempering at 200°C for a few hours. The second method gives bluish colored crystals due to reduction of the TiO_2. On heating at 600–800°C in an oxygen atmosphere, the crystals become colorless.

Dissolving the $BaCl_2$ in water, the crystals remain with the excess $BaCO_3$ from which they are readily separated.

If one uses a comparatively large amount of alkali carbonate as melt and "dissolves" stoichiometrical amounts of $BaCO_3$ and TiO_2, hexagonal and monoclinic crystals, besides small cubic ones, are obtained.

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The Reaction $He^3(n,p)H^3$ and the Neutrino Mass*

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February 13, 1948

KONOPINSKI[1] and Pruett[2] have shown that the ft value for H^3 is much lower than would be predicted by beta-theory, but that the discrepancy can be removed if it is assumed that the neutrino emitted by H^3 has a rest mass of about 0.2 that of the electron[2] (taking the H^3 end point as 11 kev[3] and the half-life as 12 years).[4] Oppenheimer[5] has suggested the possibility that nuclei of the H^3 type might emit neutrinos of finite mass while long-lived C^{14} might emit a massless neutrino. We have measured the mass of the neutrino emitted in the two disintegrations, H^3 and C^{14}, by an accurate cloud-chamber determination ot the Q value for the reactions $He^3(n,p)H^3$ and $N^{14}(n,p)C^{14}$. The neutrino mass in each case involves only the n,p mass difference, the β end point (actual, not Kurie extrapolated), and the Q value.

The nitrogen reaction is well known, but measurements of its Q value have given widely discordant results.[6] We looked for the hitherto unobserved $He^3(n,p)$ in some helium enriched in He^3 kindly supplied by Mr. Novick of this laboratory. With the cloud chamber filled with helium containing about 10^{-3} percent He^3 we were able to observe the $He^3(n,p)H^3$ reaction along with the nitrogen reaction (from a trace of nitrogen left in the helium). Figure 1 shows examples of both the N^{14} and the He^3 reactions in which the tracks of recoiling C^{14} and H^3 nuclei can be seen (chamber pressure 20 cm). The "breaks" in the tracks (marked A and B in Fig. 1) are sharp enough in the negatives so that it is possible to measure the proton part of the ranges with accuracy.

In order to determine the Q values, the relative ranges of the He^3 protons and the N^{14} protons were measured while the chamber was filled with helium. Since the stopping power of helium is not accurately known, the absolute range of the nitrogen proton was then measured with air (15-cm pressure) in the chamber. Figure 2 shows the experimental distribution of proton ranges in air (block curve) fitted to a theoretical curve including straggling and minor geometrical factors. From the mean range (R_M) determined from Fig. 1 and the stopping power of the chamber, the range in air at 76 cm and 15° is 0.991 cm, and the He^3 proton range then follows as 0.980 cm. The nitrogen proton range in air was also checked by measuring the range in the chamber of Pu α's. With the known range of Pu α's (3.68 cm), this comparison method also gave 0.991 cm as the nitrogen proton range.

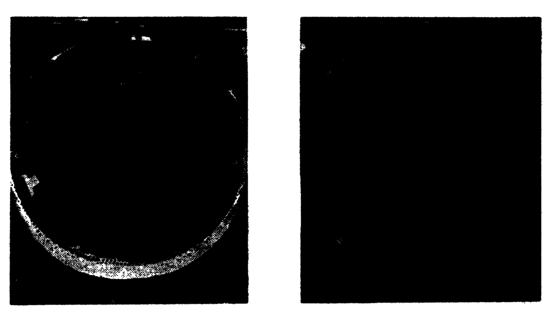
Using 751 ± 6 kev for the n,p mass difference,[7] 154 ± 7 kev for the C^{14} end point,[8] and 11 ± 2 kev for the H^3 end point,[3] we obtain the following expected values for the Q's and proton energies, where μc^2 is the neutrino rest energy:

$$He^3:\quad Q=740\text{ kev};\quad E_p=(555\pm5\text{ kev})-3/4\mu c^2,$$
$$N^{14}:\quad Q=597\text{ kev};\quad E_p=(558\pm9\text{ kev})-14/15\mu c^2.$$

The present range measurements, together with the range energy curve of Livingston and Bethe,[9] give:

$$He^3:\quad E_p=552\text{ kev }(Q=736\text{ kev});\quad \mu c^2=4\text{ kev},$$
$$N^{14}:\quad E_p=557\text{ kev }(Q=596\text{ kev});\quad \mu c^2=1\text{ kev}.$$

The error in the actual range measurement is estimated to be about 1 percent or 5 kev, but this error must be combined with the uncertainty in the range energy curve with the result that the final error is about 25 kev, which thus becomes the upper limit for the neutrino mass. However, the relative mass of the neutrino in the two cases is known much better; actually the experiment shows that the mass of the neutrino for H^3 and C^{14} is the same within about 5 kev.



$N^{14}(np)C^{14}$ $He^3(np)H^3$

FIG. 1.

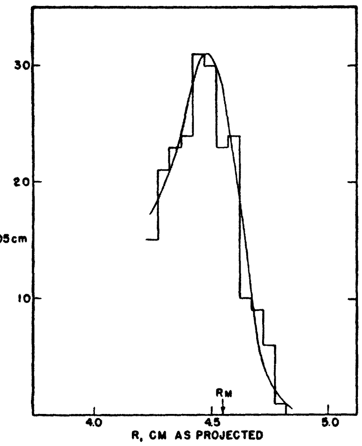


FIG. 2.

The conclusions to be drawn from this work in its present status can be summarized as follows:

(1) The C^{14} and the H^3 neutrino have the same mass within 5 kev. This finding rules out the suggestion of Oppenheimer.[5]

(2) The absolute value of the neutrino mass is within 25 kev of zero. Experiments are now under way to reduce the uncertainty by fixing the range energy curve more accurately (by photographing protons of known energy in the chamber simultaneously with the disintegration protons).

(3) The H^3 neutrino mass is definitely less than that needed to obtain conformity of the energy and lifetime with beta-theory. If the discrepancy is ascribed to the end-point energy, assuming a massless neutrino, it would necessitate an error of more than a factor of two in the 11-kev value.

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Domain Theory and the Dependence of the Coercive Force of Fine Ferromagnetic Powders on Particle Size

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FRENKEL and Dorfman[1] first predicted that sufficiently small ferromagnetic particles will each consist of a single domain and act as a permanent magnet. The present author[2] examined the situation quantitatively on the basis of modern domain theory and found the result that particles with diameters of the order of 1000A, varying somewhat with the material, may be expected to consist of a single domain; it was further pointed out that in this case the coercive force will assume unusually high values, being limited by the anisotropy energy.

The maximum intrinsic coercive force caused by anisotropy is given by the classical relation

$$H_c=2K/I_s \tag{1}$$

for cubic as well as uniaxial crystals; here H_c is the reverse field required to reverse the direction of magnetization; K is the anisotropy energy density constant, and I_s is the saturation magnetization. Values of H_c calculated for Fe, Co, and Ni are 500, 8600, and 200 oersteds, respectively, at room temperature.

Confirmation of the view that a small particle acts as a single domain is furnished by an analysis of the measurements of Guillaud[3] on the ferromagnetic compound MnBi. From Eq. (1), $H_c=2(1.2\times10^7/600)=40{,}000$, in quite fair agreement with the extrapolated experimental value deduced below. From Guillaud's data on coercivity *vs.* (diameter)$^{-1}$ plotted in Fig. 1, we may extrapolate from the observed $H_c=12{,}000$ at 3μ to a limiting value $H_c\sim25{,}000$.

In some materials the coercivity caused by anisotropy in the magnetic field energy resulting from elongated particle shape may outweigh the effect of the crystalline anisotropy energy.[4] However, the upper limit $H_c=2\pi I_s$ to the shape coercivity is only $\sim$3800 in MnBi, so that the particle shape plays a negligible role here.

The dependence of H_c on particle size, as shown in Fig. 1, may be understood qualitatively on the following picture. We consider a small sphere magnetized to saturation; when the field H_c is applied it is supposed that a domain wall forms as shown in Fig. 2. In this position the energy balance is given approximately by the equation

$$\gamma(\pi p^2/4)=H_cI_s(\pi p^2\delta/8)+\tfrac{1}{2}I_s^2V(\delta/2d). \tag{2}$$

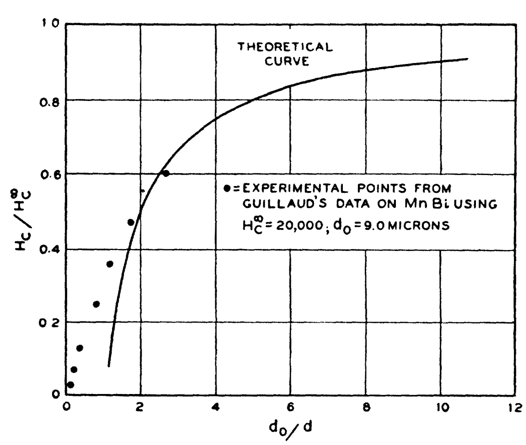
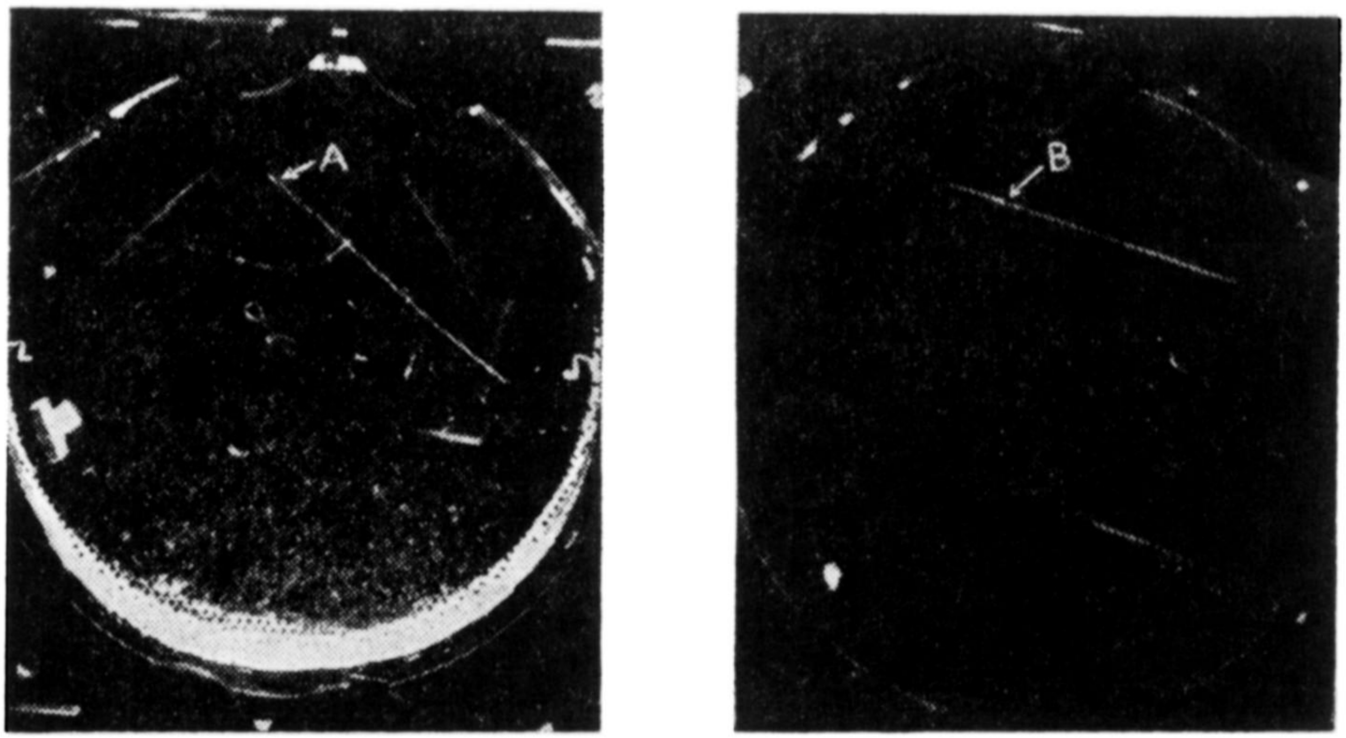


FIG. 1. Comparison of Guillaud's data with theoretical lower limit to coercive force H_c as function of particle diameter d.



$N^{14}(np)C^{14}$ $He^{3}(np)H^{3}$

FIG. 1.